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Combining paleoecological and archaeological records to inform fire management and ecosystem conservation in Killarney National Park, Ireland

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Combined paleoecological and archaeological records allow for a detailed examination of past fire–human–vegetation interactions. Focusing on a national park at risk from increasing fire threats, we explore the potential of integrated approaches to inform future fire management and conservation policy.

Fire is increasing in many natural and cultural landscapes due to ongoing climate and land-use changes (Bowman et al. 2020), with potentially long-lasting consequences on ecosystem structure and composition (Kelly et al. 2020). In Ireland, the occurrence of recent wildfires in national parks represents a key challenge for park managers. For example, on one of the hottest days in Ireland in 2021, a fire blazed through ~1400 hectares of land in Killarney National Park (KNP), severely degrading existing habitats and wildlife. The fire burned for four days and was the largest fire that had occurred within at least the last two decades.

Fires have been increasing in frequency and severity in the region in recent years; however, the scale and impact of the 2021 fire was much larger than expected. In order to mitigate the effects of such catastrophic events, there is a growing need for park managers to understand how ecosystems responded to past fire variability. In Ireland, such a long-term perspective can be provided by multi-site comparisons of archaeological and paleoecological records, offering new insights into the anthropogenic and climatic drivers of past fire regimes (Whitlock et al. 2017). Such long-term perspectives can be used to inform the development of fire management strategies appropriate for varying land-use, climate, or vegetation scenarios (e.g. Willis and Birks 2006; Colombaroli et al. 2017; Brown et al. 2018; Gillson et al. 2019).

Integrated, long-term perspectives are particularly needed in regions where forest management practices such as fire suppression and fire exclusion over the past century have led to largely fire-free landscapes. The primary goal of fire suppression/exclusion is often to protect natural heritage, e.g. semi-natural native woodlands, and is a common practice in Irish national parks. This has likely been the case for KNP since the park's creation in 1932 (and formally since at least 2005, with the creation of a fire-fighting action plan for early wildfire detection and control). Woodlands and grasslands in the park are particularly at risk from severe wildfires, causing woodland margins to recede. Here, we discuss how the combination of archaeological and paleoecological evidence can provide key information about the long-term effects of fires on landscapes, and how such integrated knowledge can better inform ecosystem management in the park.

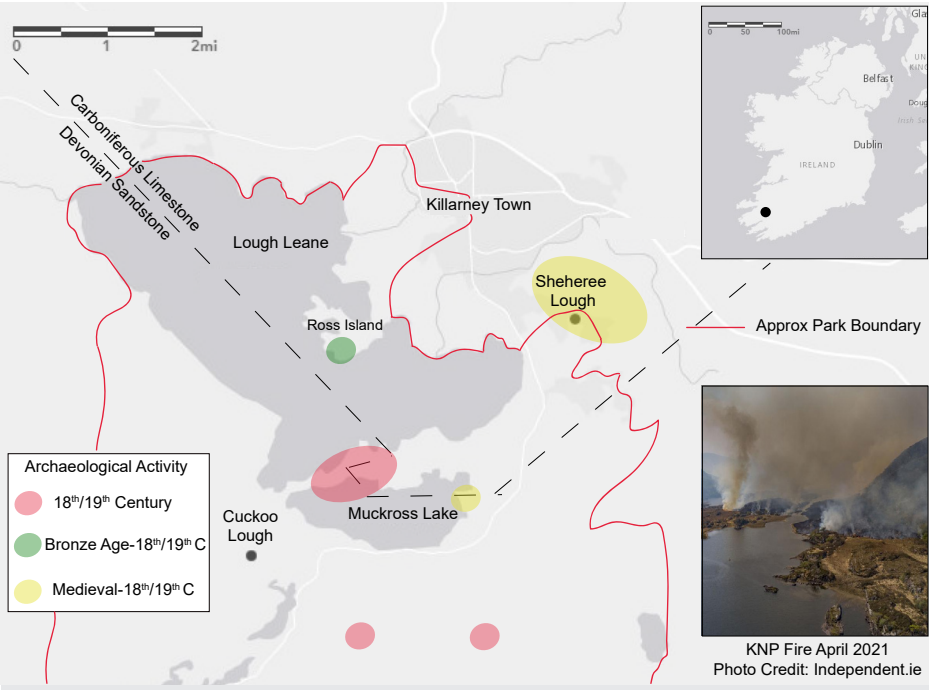

Figure 1: Map of Killarney National Park (KNP), including the location of study sites, underlying geology and archaeological activity. Inset top: location of KNP within Ireland. Inset below: fire in KNP, April 2021.

Long-term fire–vegetation–climate interactions

Pollen and charcoal records from two study sites within KNP (Cuckoo Lough: uplands, and Sheheree Lough: lowlands; Fig. 1) provide insights into past fire regimes at the transition from a semi-natural forest to the establishment of modern anthropogenic landscapes. The two sites overlie different bedrocks and elevation, thus highlighting differences in fire trajectories and vegetation development at a more local scale. Paleoecological data show that fire has been part of the Killarney landscape since at least the Late Glacial (ca. 20,000 yr cal BP), which predates all evidence for human occupation (Hawthorne and Mitchell 2018). Peaks in fire activity at ca. 8000–5000 yr cal BP in the lowlands and ca. 7000–4000 yr cal BP in the uplands, coincided with climate amelioration and increased seasonality during the early Holocene (Ghilardi and O'Connell 2013; Mitchell and Cooney 2004). A later peak in fire activity occurred in the uplands ca. 2500 yr cal BP (Fig. 2).

According to the archaeological and paleoclimatic evidence, these maximum fire conditions were largely driven by climate conditions conducive for fire, and enhanced by moderate anthropogenic activities. Climate at the time made the environment more receptive to both natural and anthropogenic fires. These fire periods are associated with an overall decline in fire-sensitive tree taxa (e.g. *Ulmus*), increases in fire-enhanced species (e.g. *Alnus*) and the expansion of open, more flammable shrubs and grasses (e.g. *Corylus* and Poaceae). Importantly, microsite conditions (altitude and bedrock) influenced how the different vegetation responded in the long-term, by promoting individual taxa locally (e.g. increases in *Corylus*, *Alnus*, *Betula*, and *Quercus* during the Late Neolithic-Bronze Age (5000–2500 yr cal BP).

The increasing role of humans driving fire and vegetation changes in the KNP

Over the last few millennia, fire controls shifted from climatic to predominantly anthropogenic. Fire disturbances increased, particularly since the Bronze Age, when a

combination of human activities in different areas of the park had a long-lasting and pervasive effect on vegetation structure and composition (Hawthorne et al. 2021).

Combined paleoecological and archaeological data show significant differences in the timing and intensity of human activity at both sites. Conditions in the uplands were less suitable for agriculture due to their lower fertility, and human activity was rather low until the 18th–19th centuries (Cuckoo Lough; Fig. 2). In contrast, in the lowlands (Sheheree Lough; Fig. 2), periods of increased fire activity (~3800 yr cal BP and ~1300 yr cal BP) roughly correspond to mining activity (e.g. between 3900–3400 and 1300–1000 yr cal BP; see O'Brien 2004), despite the wet and cool climatic conditions at that time (~4250 and 3750 yr cal BP; Swindles et al. 2013). From ~3500 yr cal BP evidence for the expansion of agriculture, suggests that these practices supported the Bronze Age mining activities on nearby Ross Island, which peaked ~3300 yr cal BP and continued until the 18th–19th centuries (O'Brien 2004). Forest decline continued in the last ~1000 years, synchronous with archaeological sites dated to the Early Medieval period. Taken together, the matching paleoecological and archaeological evidence shows the transition from ecosystems largely shaped by anthropogenic fires to the final establishment of more open landscapes, presently under more fuel-limited conditions.

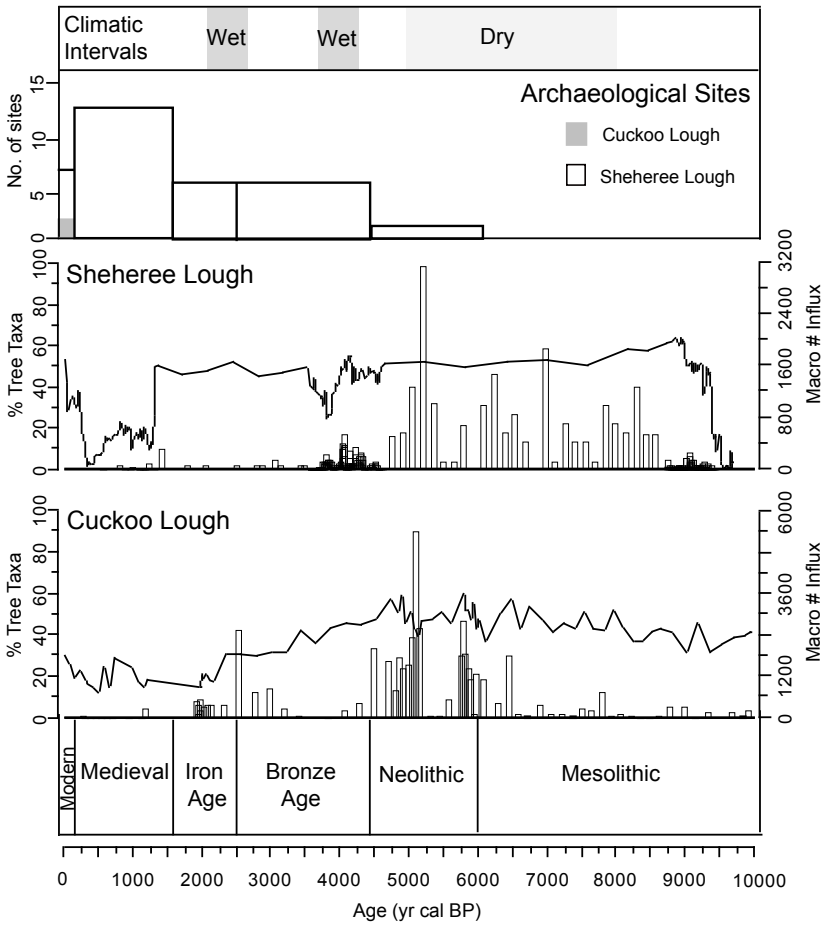

Figure 2: Summary of paleoecological and archaeological evidence from Cuckoo and Sheheree Lough, by archaeological period. Macroscopic charcoal influx (particles/cm²/yr; bars) is presented with total tree taxa (%; line). Number of archaeological sites are also presented with wet and dry climatic periods denoted from the literature.

Implications for fire management and ecosystem conservation in the park

Current fire management plans within KNP are limited to fire detection and control/suppression, with the priority of preserving the park's archaeological and natural heritage. Such management strategies are presently challenged by the occurrence of severe fire events during exceptionally dry years. The frequency and severity of fires in Ireland has been increasing in the past decade, and there is a clear and growing need for management strategies to meet these new challenges.

Paleoecological and archaeological data can assist in identifying best approaches that can guide future conservation and landscape management strategies (e.g. Gillson 2019; Whitlock et al. 2017). In the case of KNP, records show that fires were part of the park's long-term history, similar to other temperate regions (Whitlock et al. 2015, 2017). In the past, maximum fire conditions occurred when climate conditions were conducive for fires, and fire activity was intensified by moderate human impact (e.g. between the Late Neolithic-Bronze Age; Fig. 2). In the long term, such fire activity was important for maintaining species that are more fire-adapted locally (e.g. *Corylus*, *Alnus*, *Betula*). The establishment of open habitats only occurred when agricultural practices intensified, leading to marked reductions in forest biomass.

Overall, the KNP case study shows how both climatic and anthropogenic factors created a complex mosaic of vegetation communities, which supported varying fire regimes over time. These historical legacies on present landscapes are key for understanding the conservation of landscapes under current and future climates (Whitlock et al. 2017). Today, the hyper-oceanic climate of the region renders the lowland native broadleaved woodland less fire-prone; however, this may change rapidly under future warmer temperatures (de Rigo et al. 2017). In contrast, in upland areas the open land between woodland patches is dominated by the heather *Calluna vulgaris* and the grass *Molinia caerulea*, fire-prone vegetation types, which in turn could impact the edges of the woodlands. Open *Calluna vulgaris* and *Molinia caerulea* communities are maintained by grazing from deer populations; hence, a reduction in deer numbers would permit woodland expansion and, thus, reduced scope for fires under present climatic conditions. Instead, the pasture land in the lowlands is managed more intensively and tends not to support fire. A more robust, evidence-based plan for the conservation and management of the park can be achieved by conservation policies that better reflect conditions at the landscape scale, through the integration of all the available evidence, including modern, paleoecological, and archaeological.

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